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INVESTIGATIONS ON LIGHT AND HEAT, MADE AND PUBLISHED WHOLLY OR IN PART WITH APPROPRIATION FROM THE RUMFORD FUND.

III.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF HARVARD UNIVERSITY.

ON THE EXISTENCE OF CERTAIN ELEMENTS, TOGETHER WITH THE DISCOVERY OF PLATINUM, IN THE SUN.

BY C. C. HUTCHINS AND E. L. HOLDEN.

Presented by Professor John Trowbridge, March 9, 1887.

LATE in the fall of 1886 it was decided by the writers, who were then at work in the Physical Laboratory of Harvard University, to attempt a revision of some of the previous work in regard to the chemical constitution of the sun, as well as to discover, if possible, new facts bearing on the same subject. For the purpose of this investigation a magnificent diffraction grating, made by Professor Rowland of Baltimore, was kindly placed at our disposal by Professor John Trowbridge, under whose supervision and direction the subsequent work has been done.

After some delay caused by the mounting of the grating and its attachments, work was begun early in January, 1887, but, owing to bad weather and other hindrances, was not regularly and systematically prosecuted till somewhat later.

The grating used is of speculum metal with a ruled surface measuring 6 inches by 2, having 14,438 lines to the inch. It is concave, its radius of curvature being 21½ feet, and is mounted according to Professor Rowland's method. Suffice it to say, that the method is such that, by simply rolling the camera along an iron track, it passes not only from one part of the spectrum to another, but also to the spectra of different orders, at the will of the operator. As the distances on this track are proportional to the relative wave-lengths of the lines that fall successively on a given point in the camera, it is easy, by means of a suitable scale of equal parts placed beside the track, to set the centre of the photographic plate instantly within a single wave-length of any given line in the spectrum.

And here let us parenthetically state that all our wave-lengths are those given by Professor Rowland's photographic map of the solar spectrum, the position of every line referred to being carefully identified upon the map, and its absolute wave-length thus determined. Although some of the negatives contain many lines too faint to show on the map, yet we feel confident that our numbers correspond in all cases to those of the map within one tenth of a wave-length.

The light is brought into the room by means of a *porte lumière*, and then sent through the slit after total reflection by a right-angled prism. Before striking the prism it passes through a cylindrical lens, which condenses it to a band of light about 2 inches long and ⅛ inch wide. The jaws of the slit move equally in opposite directions, so that, however widely they may be opened, no lateral displacement of lines can result from this cause.

Directly in front of the slit is placed a large tin lantern containing an electric lamp; the image of the arc can be brought exactly upon the slit by means of an adjustable lens in the front of the lantern. In the lower carbon of the lamp is made a cup-shaped cavity, which is filled with the substance a spectrum of which is desired. It is not at all necessary that this be in the form of a metal, for any ordinary compound is at once reduced by the intense heat and the presence of carbon vapor to the metallic state.

The plan of working has been as follows. The apparatus being arranged as described, the sunlight is admitted and the desired portion of solar spectrum photographed upon the upper half of the plate; then the sunlight is excluded by a shutter, and the image of the electric arc containing the proper metal is allowed to fall upon the slit, and its spectrum photographed on the lower half of the plate. (Most of the plates used were those made by the M. A. Seed Co., and were cut to the size of 8 inches by 2. The most sensitive plates were obtained, and even then we found the required time of exposure for some parts of the spectrum inconveniently long.)

In order to effect the exposure of either half of the plate at will, we placed directly in front of the camera an opaque screen, in which was a rectangular opening one half the size of the plate. By turning a handle, this screen is raised or lowered without the slightest disturbance of camera or plate. The metallic spectrum, being thus photographed immediately below the solar spectrum, can be compared with it at leisure.

These spectra are then examined with the aid of a glass magnifying about ten diameters, and any coincidences between solar and metallic lines carefully noted according to their wave-lengths. In order to eliminate any personal error, they are examined by both observers separately, and their results afterwards compared.

To eliminate errors arising from suspected impurities of materials, as also from the impurities known to exist in the carbons employed, we took what we called "comparison photographs." For these, we placed in the carbon cup a portion of the substances known or suspected to be present as impurities in our metal, and then photographed the spectrum thus given on the upper half of the plate; a piece of the metal under experiment was then placed in the lamp, and the spectrum photographed on the lower part of the plate. Any lines due to impurities would then extend entirely across the plate, while those of the pure metal would extend only half-way. In addition to this precaution we consulted all accessible tables and plates as to the position of known lines of metallic spectra, and also compared together all our photographs of the same region. If all of these tests left any doubt as to the origin of a given line, it was at once subjected to special investigation until all doubt was removed.

The dispersion given by the apparatus in the order of spectrum in which we worked is such that a single wave-length occupies on the negative a space of 1.12 mm. This makes the distance between the lines D_1 and D_2 6.7 mm., while the length of spectrum from A to H is about 4.1 m. With so great dispersion it would hardly be possible to mistake the position of a line by any very considerable amount, or to confound neighboring lines belonging to different metals.

For reasons readily apparent, it was found so difficult to photograph under high dispersive power those parts of the spectrum not lying between wave-length 3600 and wave-length 5000, that our photographic work was done chiefly within those limits. It was, however, supplemented in many cases by eye observations in other portions of the spectrum.

We are convinced that there is much in the whole matter of coincidences of metallic and solar lines that needs re-examination; that something more than the mere coincidence of two or three lines out of many is necessary to establish even the probability of the presence of a metal in the sun. With the best instruments the violet portion of the solar spectrum is found to be so thickly set with fine lines, that, if a metallic line were projected upon it at random, in many places the chances for a coincidence would be even, and coincidences could not fail to occur in case of such metals as cerium and vanadium which give hundreds of lines in the arc.

Moreover, a high dispersion shows that very few lines of metals are simple and short, but, on the contrary, winged and nebulous, and complicated by a great variety of reversal phenomena. A " line " is sometimes half an inch wide on the photographic plate, or it may be split into ten by reversals.

At first, we believed that these reversals were due to defects in the ruling of the grating, but we are convinced that they are true phenomena from the following experiments. 1st. The wings continue when various portions of the grating are covered. 2d. They are the same in three successive orders of spectra. 3d. They are very different in different metals, and in some are not seen at all. 4th. We arranged a flat grating, with collimator and projecting lens, each of five feet focus, and found that with this apparatus the same phenomena appeared.

On pages 87 and 88 of " The Sun," Professor Young gives a list of elements in the sun according to the best authorities, which is followed by a list of doubtful elements. Some of these we have examined with the following results : —

Cadmium. — The coincidence of the two lines given by Lockyer at wave-lengths 4677 and 4799 is perfect. These are the only cadmium lines near, and sun lines in the vicinity are not numerous.

Lead. — The evidence for lead, due to Lockyer, is based upon three lines at 4019.7, 4058.2, and 4061.8. We have photographed these lines with the sun many times. They are broad and nebulous, and often several times reversed. Lines in solar spectrum numerous and faint. 4019.7 and 4058.2 certainly do not coincide. 4061.8 is very difficult to pronounce upon ; it may coincide.

Cerium, *Molybdenum*, *Uranium*, and *Vanadium.* — These four metals may be classed together. Lockyer finds four coincidences each for molybdenum and vanadium, three for uranium, and two for cerium. The arc spectrum of each is characterized by great complexity and vast numbers of lines. So numerous are the lines in fact, that often on the photographs the total space occupied by them is greater than the space not so occupied. A plate ten inches long may contain a thousand or so. Evidently coincidences between these and solar lines cannot fail to occur as matters of chance, and therefore prove nothing. One can easily count a hundred or so such coincidences without the slightest conviction that the connection is other than fortuitous. Of course all this is nothing against the probability of these metals being in the sun ; but at the same time those peculiarities of grouping, strength of lines, and other characteristics which occur in the case of iron and other spectra, and which alone can serve as evidence in such cases, are conspicuously absent.

Among the metals whose existence in the solar atmosphere has seemed probable, we have examined the following: —

Bismuth. — The line of the above metal at 4722.9, the only line of bismuth in the arc in that whole region, coincides perfectly with the more refrangible of a very faint pair of solar lines.

Tin. — The solitary tin line at 4525, thought by Lockyer to coincide, falls directly between two fine lines in the solar spectrum.

Silver. — Lockyer mentions a certain possibility of silver in the solar atmosphere from the apparent agreement of two of its nebulous lines with solar lines. One of these we have never been able to find in the course of many photographs of the region in which it is given by him.

We find seven lines of silver between 4000 and 4900. Of these seven, three are what Thalen calls nebulous; so broad and hazy that their true positions cannot be determined with much accuracy. These lie at about 4055.5, 4063.6, and 4212. A fourth line at 4023 is of the same general character, but has a sharp reversal which agrees with a solar line. The remaining three lines are represented in the sun, and are given by Thalen in the spark spectrum of the metal.

4476.2. Very strong line; nebulous on lower edge. Sun line strong. (Thalen, 4475.)

4668.8. Strong, solitary line. (Thalen, 4666.5.)

4874.3. Fairly strong. (Thalen, 4874.)

Thus, between the limits given above, every line of silver, as far as can be determined, coincides with a solar line.

Potassium. — We could find but two lines of potassium, the same that were examined by Lockyer, 4044.5 and 4048.35. Each line is reversed four times, which increases the difficulty of locating them exactly. 4048.35 seems to agree with a solar line. The solar line near 4044.5 is very faint, and it is next to impossible to decide the question of an agreement.

Lithium. — The blue line of lithium presents a curious case. The very broad and nebulous line has a rather sharp reversal near the centre, and somewhat toward the lower edge a broader and less clearly defined reversal. Both these reversals agree with solar lines at 4602.5 and 4603.2. It is possible that one of the reversals may be due to the presence of some other substance, say calcium; but if that were true, it would seem that both reversals would be nearly, if not quite, obliterated. Further experiment may clear the matter up. 4603.2 is given to iron by Thalen.

Platinum. — As far as we can learn, no evidence has hitherto been offered to show the occurrence of this metal in the solar atmosphere. We were somewhat surprised, therefore, upon meeting with coincidences. Between 4250 and 4950 we find 64 lines of platinum, sixteen of which agree with solar lines. The latter are at the following places: —

4291.10
4392.00 (Thalen 4389.4)
4430.40
4435.20
4440.70
4445.75 (Thalen 4442.0)
4448.05
4455.00
4481.85
4552.80 (Thalen 4551.8)
4560.30
4580.80
4852.90 (Thalen 4851.5)
4857.70
4899.00
4932.40

We have taken all possible care to make this statement accurate, and to admit no lines about which there seemed to be any question. There are seven other lines not included in the list, the probability of agreement of which is at least as good as that upon which potassium is admitted.

In all these experiments everything has been done to bring out and show upon the photograph as much as possible. The lamp, constructed for the purpose and fed by a powerful dynamo, gave an arc from a half to three fourths of an inch long, and burned with a long flame and so intense a heat that it could be worked for but a few minutes at a time. Any one who has carried out a series of experiments like this is alone competent to appreciate the great labor and the endless difficulties and perplexities that attend them.

Our thanks are especially due to Dr. Wolcott Gibbs for his hearty encouragement, and for the use of valuable apparatus and chemicals.